Transmission Loss allocation using Power Fraction Method

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***Abstract*—Transmission loss calculation for the market operations is an old problem. Loss allocation should be fair and acceptable by all market participants, transparent and easy for computation, and also would recover all of losses cost. Thus, it is important to know the contribution of individual generator in the line flows and line losses. In traditional methods like Newton-Raphson method, Guass-Seidal method only total losses are calculated. In these traditional methods identity of generator is totally lost. In this paper a new method known as power fraction method (PFM) is used to allocate the transmission losses and which give the contribution of individual generator in line A modified IEEE 30 bus system is used as a case study example for comparing the proposed method with more traditional techniques in an interconnected system.**

***Keywords*— independent system operator (ISO);market operation; power fraction method;transmission losses**

I. INTRODUCTION

The deregulation of power system introduces the competition with respect to productions, but transmission is done in traditional way. Deregulation also gives rise to new problems and challenges in front of the system operator. System loss allocation is one of the considerable problems. Dividing losses cost of system network into fractions to be paid by market participants (network users, such as generation or distribution companies), to loss compensator generators through ISO (Independent System Operator) is a complicated problem. If there is more than one power supplier, then it is necessary to charge them according to their contribution in supplying those losses. Losses are about the 3 to 8 percent of total network power and cost millions of dollars annually. Loss allocation should be fair and acceptable by all market participants, transparent and easy to computation, and also would recover all of losses cost. Thus, information about the contribution of individual generator plays an important role in pricing [1]

An Open Transmission Access (OTA) gives right to all market participants to access the system facilities and restricted just by the physical constraints. The responsibility of market participants is to incur the cost for the use in order to accommodate the transactions. The introduction of new paradigms such as competition in generation, the idea of electricity as a commodity, contracts for power exchange, future electricity markets, ISO's and so on, imply in a great impact on existing network power transactions and create an entirely new set of transactions among utilities, end users, independent power producers, etc. In this new scenario, an adequate market and efficient pricing schemes will be of great importance to increase power transfer throughout the network [1].In the process of unbundling of generation and transportation functions and privatization of independent specialized companies, many critical issues have been raised. One such problem has its origins in the fundamental nature of the transmission network. The OTA environment guarantees that generators have open access to the grid while requires the costs involved in the use of the network need to be recovered from market participants. However, the structure of the network provides a number of alternative routes by which power can flow from a generator. It is not possible to trace physically the routes of electricity from individual generators over the network. This is the source of the common or joint cost allocation problem in electricity grids [1].

II. TRADITIONAL METHODS OF LOSS ALLOCATION

As ISO knows, allocation of losses should be based on each participant is responsible for the fraction of power losses that caused it and consequently who generated more losses must pay more shares. But the main difficulty to applying this logic is that the total system losses is a nonlinearfunction of power system state variables and this makes impossible to separate this function to sum of its single variable functions and allocate it naturally. Many methods have been proposed in literature up to now [2].That we can categories them as: Pro rata, incremental transmission loss, Z-bus method,In Pro rata method that is the most popular ones, the losses is allocated to each generator or load, regarding their power injection to network,But there is not a proper distribution of loss because it's does not consider the total power injection in network [3]. This method doesn't consider the location of them or network topology. So a remote generator or load, that certainly causes more power losses, treats the same as other near network users.[3]. ITL (Incremental Transmission Losses) technique, allocate the system losses to network participant through assigning a coefficient known as ITLs to each one that represent the total network losses sensitivity to that particular user power injection [4,5]. The Z-bus loss allocation, use the total system loss formula and try to write it in the summation form of each bus complex current injection [6]. Proportional sharing principle is based on a non-provable or disprovable theorem that assumes the inflow powers are proportionally shared between the outflows power at each network bus [7,8]. In this paper, based on networks characteristics equations, a loss allocation method is proposed that canallocate the power losses of a pool power market to its users, in their terms of active power injections as well as their reactive power. So ISO may use it to separate total losses of reactive power transfer in system on the basis of individual generator contribution and allocate it to reactive market participants, or system operator can allocate this part of power losses as another part of ancillary services costs ,to market users as fair as is possible.

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III. PROPOSED METHOD

The method used in this paper gives the contribution of generator power and Transmission line losses into an element in terms of fraction, so it may be called as power fraction method. It gives two type of fraction: “Loss power fraction”corresponds to power consumption in various elements, and “Power flows fraction”, means power flow through the element. The PFM is mainly concentrated on the calculation of Transmission line losses in lines.

In this paper, PFM [9] is used for the transmission losses without losing the identity of the generator. The PFM [9] method is based on the concept of Kirchhoff state and power fractions. Kirchhoff state KS_g is nothing but a set of voltages and currents when only one generator provides input power to the network. The voltages and currents satisfy the KCL and KVL for this network. The nodal injection current vector for KS_g is denoted by

$$I_{gvec} = [0\ 0 \ldots..1 \ldots.0]^T * I_g = e_g I_g (1)$$

Current I_g is a scalar and represents the value of current injected into node g. Symbol e_g is the standard basis vector, with a magnitude “1”,in g^{th} location when node is excited and all other elements equal to zero. Nodal voltages vector V_{gvec} is given by,

$$V_{gvec} = [V_{1g} V_{2g} \ldots V_{ng}]^T = [Z_{1g} Z_{2g} \ldots Z_{ng}]^T \quad * I_g (2)$$

where, subscript n denotes number of buses $I_g$is a scalar with a different values for each Kirchhoff state and V_{1g},V_{2g} are complex numbers and represents Phasors of the Kirchhoff state, KS_g as the phase difference between all injected currents is not known apriori. Therefore the voltage or current Phasors of different Kirchhoff states are not added but the real and reactive power belonging to different Kirchhoff states are summable scalars [9]. Therefore (2) become,

$$V_{gvec} = Z *= Z * e_g I_g (3)$$

Z is a nodal impedance matrix that includes load impedance. Voltage and current in line element (branch) ‘l’, for this Kirchhoff state will be denoted by V_{1g} and I_{lg}respectively. These variables form vectors v_{Lgvec} and i_{Lgvec} of dimension L*L which represents total number of elements in the network comprising lines, loads, shunt reactors and total charging admittances at nodes. Symbol y denotes L*L primitive admittance matrix. Using (2), element voltage and current can be written as

$$v_{Lgvec} = [v_{1g} v_{2g} \ldots \ldots. v_{lg} \ldots \ldots v_{Lg}]^T = A^T * V_{gvec} (4)$$

$$i_{Lgvec} = \left[i_{1g} i_{2g} \ldots i_{Lg}\right] = yA^T * V_{gvec} = \ yA^T * Z * e_g I_g (5)$$

Matrix A is node-element incidence matrix and includes ground node. Now, from (2)

$$V_{gg} = Z_{gg} * I_g (6)$$

This represents the equivalent network at node g, shown in Fig.1.

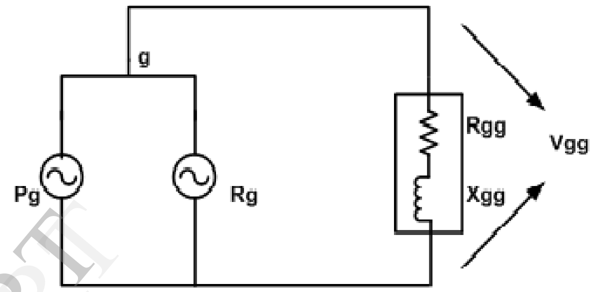


Fig. 1. Equivalent network at node ‘g’

$$I_g = \sqrt{\frac{P_g}{R_{gg}}} \qquad (7)$$

This implies that a reactive power support of magnitude

$$Q_g^s = I_g^2 * X_{gg} = \frac{P_g}{R_{gg}} X_{gg} \qquad (8)$$

is required of the source for transfer of power P_g. Then, generator currents can be obtained by simplifying (7) and (8) as

$$I_g^2 = \sqrt{\frac{P_g^2 + Q_g^2}{R_{gg}^2 + X_{gg}^2}} \qquad (9)$$

The generator voltage which appear because of injection P_g and Q_g is given by

$$V_{gg} = \sqrt{P_g R_{gg} (1 + \frac{Q_g^2}{P_g^2})} \qquad (10)$$

For a Kirchhoff state, Q_g and Q_g^s must be necessarily equal. Complex power in an element that can be obtained as

$$S_{lg} = \frac{P_g}{R_{gg}} [A_1^T Z]_{g^{th} row * l^{th} col} [Z^* A]_{g^{th} row * l^{th} col} y_l^* (11)$$

Where,l= Number of lines, g= Number of generator,

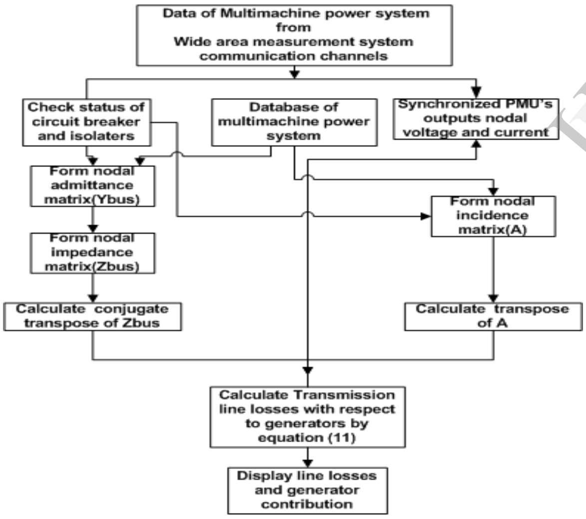
P_g= Generator power,R_{gg}=R_e(diagonal Z)ggth,
Z*=The conjugate transpose of node impedance matrix,
S_{lg}= complex power in line l injected by generator g,
Symbol * denotes the conjugate transpose.

A. Steps of power fraction method

The steps required to calculate line losses for any multimachine power system with wide area measurement system and communication channels, using power fraction method are as follow

1) Check the status of circuit breakers and isolators.
2) Collect all the data from Synchronized PMU output i.e nodal voltage and currents.
3) Form network nodal admittance matrix using information from multi-machine database and WAM system.
4) Calculate A comprising lines, loads, shunt reactant and total charging admittance at nodes as element Where, the loads are represented by their equivalent impedance.
5) Form Form A and calculate A^T
6) Calculate Z_{bus} matrix and conjugate Transpose of Z_{bus}
7) Calculate line losses along with equation (11)

B. Flow chart for Transmission line losses using Power fraction Method



IV. TRANSMISSION LOSSES

One important case is transmission loss, Active power losses are due to the resistive component of the transmission lines and it amounts to about 5 present of the total active power load. In any line, transmission loss depends on power flow. Because power flow in any line is additive over supplies from generators connected to that line, the portion of transmission loss that can be attributed to any particular participant is very much dependent upon the way its power flow shares the lines in the network. Although due to the nonlinear nature of power flow equation, it is impossible to perfectly attribute branch power flow to flows contributed by individual generators or loads [10]. Agreement on allocation of the cost of transmission loss (as well as other common costs that vary with power flow) is still very essential to promote the competition. The cost allocation problem is contentious because the flow of electricity cannot be physically traced [11].In this paper, a new method known as Power Fraction Method is used to calculate contribution of individual generator in power losses. This method can allocate the power losses of a pool power market to its users, in their terms of active power injections as well as their reactive power. So ISO may use it to separate total losses of reactive power transfer in system from losses of active power and allocate it to reactive market participants, or system operator can allocate this part of power losses as another part of ancillary services costs, to market users as fair as is possible.This paper describes the method used and formulation of case study. Modified IEEE 30-bus system is considered as case study.

V. REPRESENTATIVE CASE STUDY

The system shown in Fig.2 The system considered in this paper is 30 bus system. The generators are present at nodes and loads are connected at node numbers.

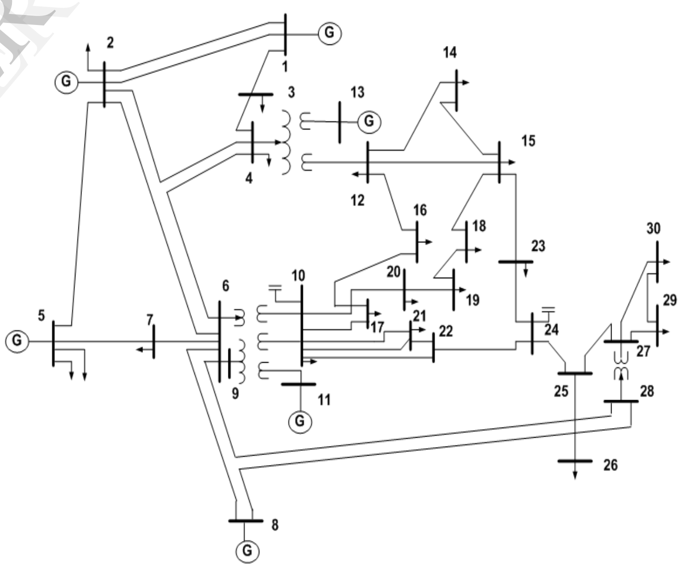


Fig. 2. IEEE 30 bus test system

TABLE I. Investigating individual Generator contribution to the line losses

From	To	Contribution G1	Contribution G2	Total
1	2	6.8474+20.5067i	0.0478 -0.1431i	6.7997+20.3636i
1	3	3.4565+12.6331i	0.1193-0.4361i	3.5758+13.0692i
2	4	0.8240 +2.5109i	0.3237-0.9864i	1.1476+3.4973i
3	4	0.9617 +2.7612i	0.0315-0.0904i	0.9931+2.8515i
2	5	2.6021+10.9322i	0.4989+2.0961i	3.1010+13.0282i
2	6	1.7567 +5.3307i	0.4670+1.4172i	2.2238+6.7478i
4	6	0.6808 +2.3684i	0.0527+0.1834i	0.7335+2.5519i
5	7	-0.1340 -0.3378i	-0.0128-0.0323i	-0.1468-0.3702i
6	7	0.3785 +1.1623i	0.0408+0.1254i	0.4193+1.2877i
6	8	0.1544 + 0.5403i	0.0242+0.0846i	0.1786+0.6250i
6	9	0.0000 +1.6594i	0.0000+0.2737i	0.0000+1.9330i
6	10	-0.0000+1.4510i	-0.0000+0.2393i	-0.0000+1.6903i
9	11	0.0000+ 0.0000i	0.0000+0.0000i	0.0000+0.0000i
9	10	-0.0000+0.8775i	-0.0000+0.1447i	-0.000+1.0223i
4	12	-0.0000+4.5240i	0.0000+0.6517i	-0.0000+5.1757i
12	13	0.0000 +0.0000i	0.0000-0.0000i	0.0000+0.0000i
12	14	0.0612+0.1273i	0.0090+0.0187i	0.0702+0.1460i
12	15	0.1666 +0.3281i	0.0235+0.0463i	0.1901+0.3744i
12	16	0.0449+0.0943i	0.0058+0.0122i	0.0507+0.1066i
14	15	0.0038 +0.0034i	0.0004+0.0004i	0.0042+0.0038i
16	17	0.0091+0.0212i	0.0010+0.0022i	0.0100+0.0234i
15	18	0.0331+0.0673i	0.0046+0.0094i	0.0377+0.0768i
18	19	0.0043 +0.0087i	0.0005+0.0011i	0.0048+0.0097i
19	20	-0.0139 -0.0279i	-0.0024-0.0047i	-0.0163-0.0326i
10	20	0.0672+0.1499i	0.011+0.0249i	0.0783+0.1748i
10	17	0.0131+0.0341i	0.0024+0.0063i	0.0155+0.0404i
10	21	0.1259+0.2709i	0.0205+0.0442i	0.1464+0.3151i
10	22	0.0199+0.0411i	0.0031+0.0063i	0.0230+0.0474i
21	23	0.0000+0.0001i	0.0000+0.0000i	0.0001+0.0001i
15	23	0.0173+0.0350i	0.0019+0.0039i	0.0193+0.0389i
22	24	0.0315+ 0.0491i	0.0049+0.0076i	0.0364+0.0566i
23	24	0.0028+0.0058i	0.0003+0.0007i	0.0032+0.0065i
24	25	-0.0192 -0.0335i	-0.0034 -0.0060i	-0.0226-0.0395i
25	26	0.0350+0.0523i	0.0055+0.0082i	0.0405+0.0605i
27	27	-0.0520-0.0992i	-0.0086-0.0165i	-0.0606-0.1157i
28	27	0.0000+1.3420i	-0.0000+0.2147i	0.0000+1.5567i
27	29	0.0679 0.1283i	0.0106+0.0200i	0.0785+0.1484i
27	30	0.1266 +0.2384i	0.0198+0.0372i	0.1464+0.2756i
29	30	0.0258 +0.0488i	0.0040+0.0076i	0.0299+0.0565i
8	28	-0.0054 -0.0170i	-0.0008-0.0026i	-0.0062-0.0196i
6	28	0.0577+0.2044i	0.0092+0.0325i	0.0668+0.2369i
				Total losses= 19.9719+77.0210i

VI. ANALYSIS

The Fig. 3 shows that the line losses with respect to Generator G1 and G2 on x-axis power in Mw and on Y-axis number of nodes are represented. TABLE I represents the contributions of generators G1 and G2 for all the lines losses. For simplicity only 30 nodes plot has been given. There are various method to allocate a transmission losses with various factor, in this paper we focus on generator contribution factor in each line If generator one contributed some more amount of power so generator pay a more money as compare to another onebecause from generator one we draw a more power so losses is also more due to more power, so on the basis of this a loss allocation is more easy costumer pay according to their availability.

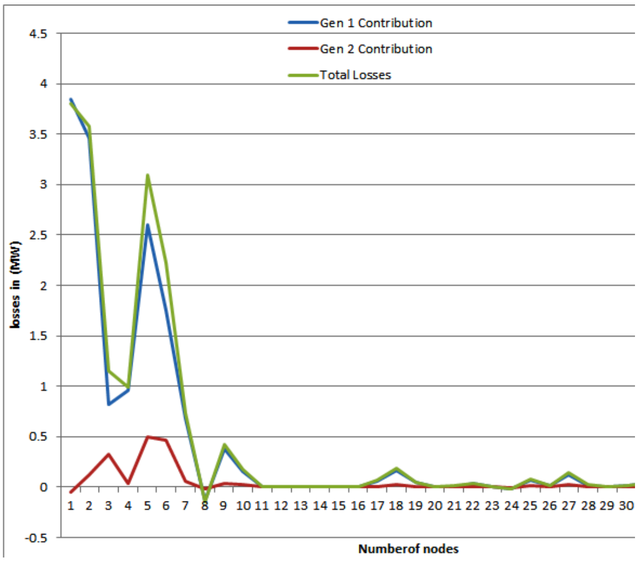


Fig. 3. Plot of losses Vs. number of nodes

VII. CONCLUSION

This paper presented a loss allocation technique which allocates transmission system losses of the electric power its participants depended on generator contribution, so the loss can allocate in network easily. Unlike the other methods the PFM method gives a contribution of each generator with line losses without considering phase angles of voltages and currents which are absolutely necessary for calculation of line losses and loss allocation There is no approximation on derived formula and it can decouple the loss share due to reactive power exchange in network from active power one. Furthermore this method just based on each participant share of generator on total system losses. The proposed method provides the possibility of line losses allocation self-compensation for all multilateral transaction and makes them completely pool market. Using this method, Transmission line losses allocation analysis is performed and the weaknesses of the transmission system have been detected and the new capacities have been suggested.

VIII. ACKNOWLEDGEMENT

The authors would like to acknowledge the support of Center of Excellence in Complex and Non-Linear Dynamical Systems (CoE-CNDS),VJTI.

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